The Productivity Slowdown: Is It the 'New Normal'?

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Abstract

This paper considers the paradoxical co-existence of a productivity slowdown and exciting new technologies. Several potential explanations are reviewed. It is argued that while some are unpersuasive it is too soon to know which carry the most weight. However, the slowdown does not appear to be an artefact of the data. A key, hotly disputed, issue is the future economic impact of today's technological progress. As with previous general purpose technologies, it is likely that there will be powerful effects but only with a lag. This has the implication that while the slowdown is real it is not necessarily permanent.

Keywords: productivity slowdown; technological progress; trend growth.

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I. Introduction

A surprising and worrying feature of the economic environment in the advanced economies in recent years has been slow productivity growth. The slowdown started before the financial crisis and weak performance has continued through the last ten years. Estimates of trend growth are now more pessimistic and projections of future economic growth have become less optimistic. Yet, at the same time, there is a great deal of excitement (or possibly angst) about quite dramatic technological change in the context of developments in artificial intelligence, the digital revolution and robotics.

This paper considers various possible (not mutually exclusive) ways to resolve this paradox. The explanations for this co-existence of rapid technological advance and disappointing growth that are reviewed include the following.

- Economic growth is faster than is captured by the national income accounts and this discrepancy has increased in the age of the digital economy.
- Even if the productivity slowdown is real, recent performance may not be a good guide to medium-term trend growth prospects.
- The financial crisis has had and continues to have a significant adverse effect on productivity growth but eventually there will be a return to business as usual.
- The problem is declining business dynamism which offsets the positive impact of new technologies.
- Important new technologies have a strong impact on productivity only after a significant time lag.
- The new technologies may seem impressive but their economic impact is and will be modest; they will not match the 'great inventions' of the past.
- The productivity of R and D has declined and across the whole economy new ideas have become harder to find.

The first two of these explanations relate to the quality of the evidence for a sustained productivity slowdown while the last five take the slowdown to be real and seek to understand why it has happened despite the apparent potential of exciting new technologies.

It should be said straightaway that it is not at all clear what the right answer is but some of these hypotheses do seem more plausible than others. The issue is important because it has a strong bearing on what is to be believed about growth prospects over the medium term. The evidence that is examined largely relates to the United States partly because the literature is much richer but also because, as the economy at the frontier, its prospects matter a lot.

II. Recent Productivity Growth

An overview of the experience of labour productivity growth in the EU15 and the United States is given in Table 1. Real GDP per hour worked in the EU15 fell substantially in successive periods prior to the crisis. The rapid catch-up growth of the early post-war decades was superseded by strong if not spectacular growth until the mid-1990s but then fell to a rather disappointing performance in the pre-crisis new economy years. The recent past, during and after the crisis, has amounted to a 'lost decade'. The United States as the leading economy has had a somewhat different history.

Strong productivity growth up to the early 1970s was followed by a marked slowdown but then there was a notable revival around the turn of the century which had, however, already waned before the crisis. The crisis years were difficult but productivity growth held up better than in Europe.

Current mainstream projections for medium-term growth in the United States and Western Europe are also displayed in Table 1. Although recovery from the dismal performance of the last few years is envisaged, the scaling down of projected growth compared with pre-2007 is quite marked. Compared with growth during the years 1995-2007, future American and European growth of real GDP per person is seen as likely to be halved or worse. In each case, a serious weakening of labour productivity growth is also expected.

It is also useful to consider the sources of economic growth. Standard growth accounting methods are used to do this in Table 2. In these estimates, TFP growth is obviously of interest since it is impacted by technological progress. In a pure textbook setting that is all it would entail. Here it is obtained as a residual and could also reflect improvements in the efficiency of input use, economies of scale or changes in capacity utilization. In particular, the very rapid TFP growth in Europe prior to 1973 benefited considerably from a transitory phase of improving efficiency in a context of catch-up growth. Similarly, the lack of TFP growth in recent years is surely influenced by the effects of the crisis working through misallocation of resources and excess capacity. Nevertheless, the decline and fall of TFP growth is striking and intensifies the productivity paradox.

An important reason for pessimism about future growth prospects is econometric evidence based on various time-series methods that trend growth of labour productivity and TFP both in Europe and also in the United States is now considerably lower than at the start of the 21st century. For example, Table 3 displays estimates made by a team of OECD economists. The implication is that recent experience is not just a temporary slowdown but that productivity growth prospects are much worse than 15 years ago.

III. Does Real GDP Measure Growth Well?

One way to explain the co-existence of slow growth and apparently rapid technological change might be that growth is under-estimated by the national income accounts either because they are conceptually inadequate or because GDP is not well estimated.[1] These problems are, of course, not new although they may well have increased as the digital revolution has progressed. However, if they are to explain the productivity slowdown rather than account for a continuing tendency for growth to be faster than stated in the Blue Book, then they must have become much more serious in a short space of time.

Compiling estimates of GDP in current prices has undoubtedly become more challenging in the digital age (Ahmad and Schreyer, 2016; Bean, 2016). Problems include collecting data on the sharing economy, taking account of digital services which are not directly paid for, and dealing with the

[1] For example, it is well-known that conventional measurement of TFP growth does not take account of the use of natural capital in production. In principle, if this slowed down, then measured TFP growth would fall. In practice, this does not seem likely to explain the TFP slowdown in the United States since the adjustment to measured TFP growth for the use of natural capital is small – on average plus 0.02 percentage points per year during 1986-2008 (Brandt et al., 2017).

movement of activities across the boundary from market to home production. The first of these is a question of tracking transactions that are prone to disappear into the shadow economy and the second could be addressed (imperfectly) by assuming that the value added can be approximated by advertising expenditures that finance their production or finding ingenious methods to infer the user valuation of these services. An alternative way of valuing consumption of internet services is by estimating the value of time spent online and this might also be used to monetize home production. In every case, however, estimates are subject to large margins of error.

In the case of home production, there are good reasons for not including it in GDP if this is intended to be a measure of market-sector economic activity that is useful for macroeconomic policy. If, on the other hand, the aim is to measure changes in economic welfare then, for example, incremental consumer surplus from time spent online is a component that should be captured and indeed may be an important aspect of the benefits of recent technological advance.

A further set of issues arise when trying to measure the growth of real GDP through time because of the difficulties of deflating estimates in current prices into constant prices. These are in large part a consequence of technological change together with the quality change and new goods and services that it delivers. There is general agreement that inflation tends to be over-estimated and, accordingly, real GDP growth is under-estimated, possibly quite significantly, by the practices currently used by government statistical offices. The literature which mainly concerns the United States, has, for example, highlighted not taking quality change in most of the economy seriously (Feldstein, 2017), the use of inappropriate imputation of prices where old goods are replaced by new goods (Aghion et al, 2017), and failures adequately to track declines in the prices of IT equipment and IT services (Byrne and Corrado, 2017).

It is not difficult to think that technological progress is responsible for the growth rate of real GDP in the United States to be perhaps 1 percentage point per year faster than officially stated. Mismeasurement of real GDP growth does not, however, explain much if any of the productivity slowdown. This is because the problems outlined above are not new and, in some cases, were more serious in earlier years, or their impact is too small to account for much of the productivity shortfall (Byrne et al., 2016). Thus, the 'missing growth' estimated by Aghion et al. (2017) rose from 0.52 in 1983-2005 to 0.69 per cent per year in 2006-13 compared with a decrease in real GDP growth from 2.06 to 1.59 per cent per year while the corrections to ICT prices proposed by Byrne and Corrado (2017) would add 0.4 percentage points to American growth between 1995 and 2006 but only 0.2 percentage points between 2006 and 2015.

On top of this it is interesting also to consider the incremental consumer surplus from internet services which surely contributes to growth of living standards even though it would be counted conventionally as adding to home production rather than GDP. A number of studies for the United States based on a variety of methodologies are reviewed and updated by Syverson (2017). They mostly indicate a missing welfare gain of between 2.5 and 5 per cent of the shortfall in American GDP in 2015 relative to its size if labour productivity growth had continued at the pre-2005 rate. By far the largest estimate of the consumer-surplus gain is derived using estimates of time spent on internet use valued at the average wage and this amounts to $842 billion for the ten years to 2015. This would be an impressive contribution to increasing living standards but is surely an upper bound.[2] Even so, it is less than a third of the $2.7 trillion shortfall from the productivity slowdown.[3] Put another way, adding it into GDP would raise productivity growth by about 0.4 percent points per year during 2005-15 compared with a slowdown of 1.3 percentage points.[4]

In other words, measurement issues can help to explain part of the new productivity paradox. Real GDP growth is significantly understated by the national accounts and, as is always the case, some of the welfare gains from technological change occur outside the scope of GDP. However, it seems unlikely that mismeasurement plays a large part in the recent marked decline in productivity growth. The evidence relates to the United States but there is every reason to think that the same analysis also applies to the UK.

IV. Is Productivity Growth Predictable?

Technological change is the ultimate source of sustained growth of labor productivity and thus of long-run increases in living standards. In a conventional neoclassical growth model, it will be represented by the growth of total factor productivity (TFP). Here the rate of growth of the capital stock is endogenous and, in the steady state, is equal to the exogenous natural rate of growth. Thus, a rise in the TFP growth rate induces capital accumulation and the steady-state rate of labour productivity growth is proportional to TFP growth. So, for projections of the rate of growth of potential output, the future TFP growth rate is the fundamental building block. In a world-leading economy (United States) this will be largely based on domestic innovative activity but in follower economies (Western Europe) mainly on technology transfer to exploit opportunities arising from TFP growth at the frontier.

Crafts and Mills (2017) find that a forecast of TFP growth for the United States business sector based on estimated trends over the previous 20- or 25-year window exhibits considerable variation and does not show monotonic decreases.[5] From a level around 2 per cent at the start of the 1970s, these forecasts are generally falling until they reach lows of about 0.5 per cent at times in the 1990s before rising to about 1.2 per cent in the mid-2000s, and then falling back to 1990s levels more recently. Average realized TFP growth (adjusted for capacity utilization) over 10 year intervals – the horizon for which the Congressional Budget Office makes projections – has also varied substantially over time. The outturn fell from 2.0 per cent per year or a little less for intervals starting in the 1960s to 0.5 per cent per year or a little more for intervals from the early-1970s to the late 1980s. It then rose to a peak of 2.0 per cent in the mid-1990s for the years encompassing the height of the 'new economy' before falling back to below 0.5 per cent per year for the period of the financial crisis and its aftermath.

If future American TFP growth is a key determinant of future trend labour productivity growth in Europe, how easy is it to forecast and is recent trend TFP growth a good guide to future medium-

[2] The estimate is obtained by updating Goolsbee and Klenow (2006) using 'expansive assumptions'.
[3] A subsequent paper looks in detail at the value of the user data obtained by Facebook and of the fees that Wikipedia could extract through charges for subscribers and concludes that together they would account for less than 0.1 per cent of GDP in 2016 (Ahmad et al., 2017).
[4] Bean (2016) suggests that if a similar method is applied to the UK the addition to productivity growth would be 0.66 percentage points per year. This is substantial but much less than the slowdown recorded in Table 2.
[5] These forecasts are derived using a basic unobserved component model where trend growth follows a random walk and the noise is a first order autoregression. This is estimated on the basis of the historical data up to that point; for details see Crafts and Mills (2017).

term performance? As Figure 1 underlines, the answers are 'extremely difficult' and 'definitely not'. The 10-year-ahead projection for TFP growth which graphs the average TFP growth rate over the next ten years shows considerable variability within a range from 2.0 to 0.3 per cent per year. Also plotted in the graph are estimates of trend TFP growth at the same point in time. Forecasting on this basis would have missed the productivity slowdown of the 1970s, the 'new-economy' acceleration of the mid-1990s, and the slowdown of recent years – in other words, all the major episodes during the period!

The implication is that an econometric estimate of low trend productivity growth currently does not necessarily rule out a productivity surge in the near future.[6] The precedent of the 1990s is witness to this. Econometrics is inherently backward looking and gives no weight to information about future technological progress. A techno-optimist should not feel too dismayed by the results of time-series analysis.

V. Is the Financial Crisis to Blame?

Another way to resolve the slow growth with rapid technological change paradox might be to suppose that adverse effects of the financial crisis have damaged the economy and offset or postponed the impact of new technologies. It is well-known that financial crises can have permanent effects on the level of potential output. Thinking in terms of a production function or growth accounting, there may be an impact on capital inputs as investment is interrupted, on human capital if skills are lost, on labour inputs through increases in equilibrium unemployment, and on TFP if R & D is cut back or if innovative firms cannot get finance.

The transition period while the levels effect materializes, and during which growth rates are depressed, may be quite long. Moreover, recovery is often slow; Reinhart and Rogoff (2014) estimated that the median length of time before real GDP per person returns to its pre-crisis level is 6.5 years. This could imply that recent labour productivity performance partly reflects a levels effect resulting from the financial crisis. Oulton and Sebastia-Barrel (2017) found a long-run impact on the level of labour productivity of 1.1 per cent per year that the crisis lasts. An analysis by OECD economists found that the median post-2007 decline in potential output in OECD countries affected by a banking crisis had reached 5.5 per cent by 2014 compared with 2 per cent in countries which did not have such a crisis (Ollivaud and Turner, 2015).

There is also good reason to think that the crisis has had significant temporary effects on productivity performance which compounded earlier weakness and which may not yet have completely evaporated. There is evidence that the crisis had led to some impairment of resource reallocation which has decreased efficiency (and thus TFP), as well as holding back implementation of innovations thus exacerbating the productivity slowdown. For the UK the main channel may be misallocation of labour as new hires and employment growth have been disproportionately concentrated in low productivity sectors with the implication that as much as two-thirds of the shortfall in labour productivity (compared with a pre-crisis projection) may be explained (Patterson et al., 2016).

[6] Estimates of trends at the end of the sample period with no future observations in the data set are notoriously unreliable as has been apparent in attempts to track the output gap in real-time; see for example, Watson (2007) and Orphanides and van Norden (2002).

There is evidence of misallocation of capital in some European countries linked to higher barriers to entry and exit resulting from costly credit, regulations, and uncertainty which has had a cumulative adverse impact on TFP growth in 2012 of about a quarter in Spain and almost a half in France (Gamberoni et al., 2016). The delayed exit of zombie firms has also had a small negative effect on the level of TFP of about 0.6 percentage points on average in 2011 (Adalat McGowan et al., 2017). TFP growth has fallen by a significantly larger amount across OECD countries in firms which entered the crisis with weak balance sheets and were exposed to a greater interruption to credit supply; Duval et al. (2017) estimate that this could account for as much as a third of the reduction in TFP growth with an impact that persisted through at least 2013.

Evidence of the implications of the financial crisis for productivity performance is gradually mounting but a full audit is not yet available. It is, however, clear that the crisis and its aftermath complicate understanding of productivity performance. The end-sample estimation of trend growth which is always problematic becomes still more difficult. Even so, there are good reasons to think that the crisis has led to a period of prolonged but nevertheless at least partly transitory weakness which may be conducive to undue pessimism about future prospects.

VI. Is the Productivity Slowdown Due to Declining Business Dynamism?

The pre-crisis slowdown in TFP growth was widespread across the American economy. It affected all regions (Cardarelli and Lusinyan, 2015) and most sectors. While a reduction in the contribution of ICT to overall TFP growth was certainly not trivial it only accounted for about a third of the post-2004 slowdown (Byrne et al., 2013). This suggests that the standard explanations for the productivity slowdown, which are based on a decline in the rate of technological progress reflected in slowing TFP growth pre-crisis subsequently exacerbated by side-effects of the crisis, may be incomplete or even misleading. It may be important to look closely at the contribution of decreases in the efficiency with which resources were reallocated to new uses which could dampen or even offset the favourable impact of new technologies.

This idea is central to an alternative hypothesis to explain the slowdown, namely, that it largely reflects 'declining business dynamism', i.e., the process of entry, exit, expansion and contraction of enterprises which might also be described as creative destruction. The symptoms of the problem are declining rates of business start-ups, job reallocation, and the share of employment in young firms. All these indicators have experienced a continual significant decline since the 1980s (Haltiwanger, 2017). Decker et al. (2017), who are advocates of declining dynamism, perform an accounting decomposition of the growth of labour productivity which attributes the (pre-crisis) slowdown between the late-1990s and the mid-2000s to much smaller contributions from entry of new firms and the covariance of employment shares and productivity growth among continuing firms.[7] It must be emphasized that this exercise does not show that declining dynamism caused the productivity slowdown – for example, it does not rule out reverse causality. Since the underlying reasons for declining dynamism are not explained it is also not clear what policy response would be appropriate.

If business dynamism has declined with adverse consequences for productivity growth, what might be the explanation? The most obvious candidates are decreases in competition and increasing

[7] The methodology employed by Decker et al. (2017) is a dynamic Olley-Pakes decomposition.

regulation both of which are clearly visible in the recent past. The Herfindahl index of industrial concentration rose in 70 per cent of American industries between 1987 and 2007 and by at least 20 per cent in 56 per cent of industries (Peltzman, 2014). De Loecker and Eeckhout (2017) found that the average price-cost mark-up for publicly traded firms in the United States rose from 1.18 to 1.67 between 1980 and 2014 and tended to rise across all sectors. Weaker competition would seem to be a possible explanation for declining dynamism but the link remains to be demonstrated.

Measures of regulatory stringency in the 'RegData' database show substantial increases in many sectors since the mid 1980s (Al-Ubaydli and McLaughlin, 2017). However, regression analysis based on these data rejects the hypothesis that regulatory stringency is responsible for the symptoms of declining dynamism (Goldschlag and Tabarrok, 2015). Similarly, panel regressions show no impact of regulatory stringency on TFP growth at the industry level (Fernald et al., 2017). So, the evidence is against claims that stricter regulation explains either declining dynamism or the productivity slowdown.

In sum, it is important to recognize that the economic impact of technological advance depends on the actions of firms informed by incentive structures, as is evidenced by the sorry example of many European countries during the ICT revolution (Cette and Lopez, 2012). If there has been a permanent reduction in business dynamism in the United States, this might partly explain the productivity paradox but it is too soon to tell.[8] The evidence for a causal relationship has not yet been established nor is there a good explanation for declining dynamism.[9]

VII. Does the Productivity Impact of a GPT Arrive Straightaway?

A General Purpose Technology (GPT) has been defined as 'a single generic technology, recognizable as such over its whole lifetime, that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects' (Lipsey et al., 2005, p. 98). Famous examples include steam, electricity and ICT. Perhaps artificial intelligence, machine learning and robotics will come to be seen as a GPT in due course.

As is suggested by the definition, the impact of a GPT on productivity typically is modest initially but then increases over time. This is implied by the arithmetic of growth accounting, which is set out in the notes to Table 4, since β and ω will be very small in the early days. At a deeper level, the reasons for the lags include improvements to the technology over time which increase its range of applications, reductions in the quality-adjusted price of the capital equipment in which it is embodied, and the time taken to implement complementary investments in organizational change.

The examples of electricity and steam illustrate some of these points. The big impact of electricity in the United States came in the 1920s about 40 years after Thomas Edison first distributed electrical

[8] The major research project on management quality (Bloom et al., 2016) has demonstrated conclusively that it has a strong effect on productivity performance which might raise the question as to whether declining quality of management is a candidate to explain the productivity slowdown in the United States. These authors have not published data on changes over time in the quality of management and their surveys were not really designed to address this question. However, the evidence such as it is does not suggest that a deterioration in management quality is a plausible explanation (personal communication from John van Reenen, October 2017).

[9] It should also be noted that there was a surge, albeit temporary, in TFP growth in the 1990s at a time when the symptoms of declining dynamism were already showing up.

power in New York in 1882. The productivity gains came from the redesign of American factories which electricity facilitated but took time to be recognized and implemented and were realized through TFP spillovers (David, 1991).[10] The impact of steam power on productivity growth in Britain was negligible prior to 1830 when only 165,000 horsepower was in use even though James Watt's patent was issued in 1769 (Crafts, 2004). The cost effectiveness and diffusion of steam power was held back by the high coal consumption of the original low-pressure engines and the move to high pressure – which benefited not only factories but railways and steam ships - was not generally accomplished until the second half of the 19th century. The science of the steam engine was not well understood and the price of steam power fell very slowly, especially before about 1850.

Table 4 compares the impact of the three most famous GPTs. The estimates reflect delays before maximum impact on productivity growth rates. The eventual impacts are substantial in each case. The price falls recorded in the table can be thought of as a measure of the rate of improvement of the technology which means that ICT was much faster than electricity which in turn was much faster than steam. Arguably, western societies have been getting better at exploiting new technological opportunities so that the impacts are felt more quickly. This would perhaps not be surprising in the context of superior scientific and technological capabilities, greater expenditure on R and D, and more sophisticated capital markets.

The economic impact of important new technologies takes time to materialize and the full effect is certainly not felt straightaway. It is quite possible that their contribution to annual productivity growth is always modest even though their cumulative impact is large. A possible resolution of the current productivity paradox may well entail the timing of the economic effects of technologies which are already visible but have not yet fully matured.

VIII. Is the Problem Not Matching the Economic Impact of the 'Great Inventions'?

A possible explanation for the productivity paradox is that there is a great deal of much-noticed innovative activity but it will have only a relatively weak economic impact, i.e, only a modest effect on TFP growth or labour productivity growth. This view has been strongly advocated by Gordon (2016) who argues that the phase of rapid American TFP growth in the 20th century was based on the 'great inventions' of the second industrial revolution, that nothing of similar importance is likely in the near future, and that whatever potential new technologies like robotics have will continue only be realized slowly so that the rate of productivity growth will not be raised very much.

Gordon sees TFP growth of about 0.4 per cent per year in the business sector over the next 25 years. This is a stark contrast with Brynjolfsson and McAfee (2014), the 'techno-optimists' who stress the potential of artificial intelligence and big data and expect TFP growth of at least 2.0 per cent per year. This makes the point that taking into account assessments of future technological outcomes can led to a wide range of projections for future productivity growth very different what might result from econometric analysis of past performance.

[10] In principle, unremunerated TFP spillover effects are distinct from the capital-deepening contribution to labour productivity growth from investment in new forms of capital goods which embody the GPT. They essentially represent externalities, for example, in the form of learning effects which enhance TFP. In practice, they are hard to measure and are omitted from nearly all growth accounting studies hence their appearance in only one row of Table 4.

Gordon's claims about the past and future of 'great inventions' both deserve to be challenged. With regard to the future, several serious research studies see substantial productivity potential in new technologies such as artificial intelligence and robotics which they expect to materialize in the next 20 years or so. Frey and Osborne (2017) estimated that 47 per cent of 2010 employment in the United States has at least a 70 per cent chance of being computerized by 2035. Future advances will come in machine learning which will be applied in mobile robotics as hitherto non-routine tasks are turned into well-defined problems, in particular using big data which will allow substitution of (much cheaper) robots for labour in a wide range of low-wage service occupations. Arntz et al. (2016) consider tasks rather than occupations and see relatively few jobs (perhaps 9 per cent) as completely automatable but, nevertheless, estimate that between 35 and 45 per cent of tasks in OECD countries will be susceptible of automatibility. If either of these estimates is correct, the upside is that this technology alone could deliver labour productivity gains equivalent to, say, 1.5 per cent per year over the next 20 years. A wider perspective which encompasses driverless cars, universal multi-jointed robots and data-driven expert systems sees labour productivity growth of 2.5 per cent per year as attainable in Europe (Bartelsman, 2013).

A recent paper quantifies sectoral contributions to American TFP growth before World War II (Bakker et al., 2017). It concludes that the great inventions made a strong but not dominant contribution. Their absolute impact was actually not very different from the IT sectors in the last 40 years while the proportion of TFP growth that they contributed was lower (see Table 5).[11] Compared with recent years, the striking feature of the pre-war American economy is actually how broadly-based TFP growth was and how much accrued from the non-great-invention sectors.

So, great inventions do matter but they do not make all the difference and they may not all be in the past. A great-inventions perspective on productivity growth is misleading; a substantial component of TFP growth comes from mundane real cost reduction as Harberger (1998) reminded us. Nevertheless, if we do consider the prospects for exciting new technologies to come on stream in the next couple of decades, it seems fair to say that Gordon's pessimism is not widely shared and that the stronger evidence has been produced by researchers who see the potential for significant and rapid productivity advance.

IX. Does Declining Productivity of R and D mean that there is No Escape from the Productivity Slowdown?

Something which is not to blame for the productivity slowdown in advanced economies is a reduction in expenditure on R & D (cf. Table 6). On average in the last 50 years, the United States has spent about 2.5 per cent of GDP on R & D but while research effort has been sustained productivity growth has fallen. This is in stark contrast to the predictions of endogenous growth models such as that of Romer (1990) where in the long-run TFP growth is proportional to research intensity. An obvious implication is that a simplistic solution of tackling the productivity slowdown with increased subsidies to R & D is unlikely to be successful.

[11] The calculations reported in Table 6 offer two variants depending on whether distribution is classified as a great-invention sector (as Gordon does) or not. Gordon's classification appears to be based on the assumption that TFP growth in this sector relied on spillovers from the development of motor transport which allowed supermarkets to replace corner stores. This would presumably be an upper bound and the sector would not be included in a conventional account of the inventions of the second industrial revolution.

Not surprisingly, an econometric analysis of recent American experience rejects the endogenous growth hypothesis but finds support for a semi-endogenous growth model in which there are diminishing returns to R & D so that raising the rate of investment in R & D only has a levels effect on income per person (Kruse-Andersen, 2017).[12] Over the long run, growth in employment (which increases the knowledge base of the economy) is the only source of endogenous growth. If the insights of this analysis are accepted, then it has quite severe future implications. It suggests that the productivity slowdown reflects the ending of transitory boosts to productivity growth from past increases in R & D intensity and will be permanent in the context of falling employment growth.[13]

The long-run American experience of lower TFP growth combined with increased research intensity has been interpreted by Bloom et al. (2017) as a signal that it is increasingly difficult to find new ideas – the ideas production function is subject to severely diminishing returns. They estimate that this history implies that for the economy as a whole the number of researchers has to double every 13 years just to maintain TFP growth at a constant rate. They note interesting examples of the phenomenon at the micro level, the most striking of which is that it now takes 15 times more researchers than in the early 1970s to maintain Moore's Law.[14]

If this interpretation is correct and nothing changes, then the future for productivity growth is bleak – less favourable than even Gordon supposes. It is not just that there are no 'great inventions' around at the moment but that we should not expect much TFP growth at all in future. Fortunately, there are reasons to be more optimistic.

The key issue with regard to the past is whether it is misleading to equate TFP growth with technological progress or the growth of ideas. While this might be valid on the basis of textbook assumptions, in practice changes in measured TFP growth may be affected by the incidence of scale economies, changes in allocative efficiency, or variations in the extent to which the conventional assumptions used to infer TFP growth are inaccurate (Crafts and Mills, 2005). If TFP growth has been undermined by a loss of dynamism, this would also make TFP growth an inappropriate measure of the productivity of researchers.

This suggests that it is useful to consider other indicators of the productivity of researchers, for example, books on new technology or patents, as in Table 7. Taken at face value, these metrics argue for a much less pessimistic view of the ideas production function.[15] In the case of the patent statistics, the half-life for research productivity is 114 rather than 13 years, and in the case of tech books there is no sign of diminishing returns.

[12] This is analogous to the impact of raising the savings rate in the Solow growth model.

[13] In Kruse-Andersen's model, TFP growth converges to half the rate of employment growth. Compared with an average of 1.5 per cent annual increase in potential labour supply over 1950 to 2015, CBO (2016) projects a fall to 0.5 per cent over the next 10 years. If this continues, this model would project TFP growth at 0.25 per cent per year in steady-state.

[14] Moore's Law is an observation that the number of transistors/square inch on an integrated circuit doubles every 2 years.

[15] Alexopoulos and Cohen (2011) provide a strong justification for the volume of new technology books as a useful indicator of technological progress. As is well-known, patent statistics are not easy to interpret but they probably do indicate an increase in research productivity in the United States since the mid-1980s (Fink et al., 2016).

With regard to the future, a techno-optimistic view would be that in the digital world we can expect to see significant and sustained increases in the productivity of R & D. In particular, it will be possible to accumulate and analyze data much more quickly and thoroughly.[16] Combined with a larger stock of existing knowledge, this will facilitate recombinant innovation, mixing and remixing ideas (Brynjolfsson and McAfee, 2014). In this view, the suggestion that all the low-hanging fruit has been picked seems to be the wrong metaphor.

It seems clear that a model of endogenous growth based on R & D is not consistent with past American experience and that there probably have been diminishing returns to R & D. It is possible, however, to believe that these are a good deal less severe than a comparison of TFP with R & D expenditure seems to imply so that the positive impact of increase in R & D on productivity growth would take quite a long time to evaporate. A key aspect of the digital revolution is what impact it has on the productivity of researchers in future. If, as techno-optimists hope, this is a big positive shock, that may offer an escape route from the productivity slowdown.

X. Conclusions

I have reviewed seven hypotheses that might explain the paradox of apparently rapid technological progress co-existing with slow productivity growth. Two of these arguments relate to the strength of the evidence for a real and prolonged retardation of productivity growth. The suggestion that the productivity slowdown is a statistical artefact is not convincing even though there is good reason to believe that economic growth is underestimated by the national income accounts. On the other hand, econometric analyses which suggest that the slowdown should be seen as a reflection of lower trend growth in TFP are probably not a good guide to the future in particular because they cannot take account of the prospects for future technological change.

The other hypotheses seek to explain, rather than to explain away, the productivity slowdown but they have differing implications as to whether it is a 'new normal' that will prevail over the medium- to long-term. Two, namely, a loss of business dynamism and adverse effects of the financial crisis concern the efficient allocation of resources and there is some evidence in favour of both. The former could indicate that the future will be one in which productivity growth continues to be impaired whereas the latter is most likely a transitory phenomenon. With regard to the loss of business dynamism, possible symptoms can be seen but it is important to remember that causality has not been established and the claim that regulation is to blame remains unproven.

The final three hypotheses are about the productivity implications of future technological progress for which there are a wide range of projections for the medium term ranging from TFP growth of 0.4 to 2.0 per cent per year. Pessimistic arguments are of two kinds. Either the economic impact of today's new technologies will be rather weak or, even more ominously, new ideas have become hard to find and the steady-state rate of TFP growth is now very slow by past standards. A counter claim is that technologies such as artificial intelligence, cloud computing, robotics, autonomous cars etc. have enormous potential but this will take time to materialize. My reading of the evidence is that there is a decent chance that technological progress will deliver a revival of productivity growth in the medium term.

[16] In the words of Mokyr (2013), "Scientists can now find the tiniest needles in data haystacks as large as Montana in a fraction of a second".

In sum, it seems that the productivity slowdown is real but not necessarily permanent.

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Table 1. Growth Rates in Different Periods (% per year)

	United States Real GDP/Person	*United States Real GDP/Hour Worked*	*EU 15 Real GDP/Person*	*EU 15 Real GDP/Hour Worked*
1950-1973	2.5	2.6	4.0	4.9
1973-1995	1.7	1.3	1.9	2.5
1995-2007	2.2	2.2	2.0	1.5
2007-2016	0.4	0.9	-0.1	0.4
2014-2023			1.0	0.8
2016-2026	1.0	1.4		

Note: EU 15 is the aggregate of the 15 EU member states prior to the 2004 expansion of the European Union.

Sources: The Conference Board (2016); Havik et al. (2014); United States Congressional Budget Office (2016)

Table 2. Contributions to Growth in Market Sector, 1950-2015 (% per year).

	Education	*Capital per Hour Worked*	*TFP*	*Labour Productivity Growth*
France				
1950-1973	0.5	1.7	3.0	5.2
1973-1995	0.2	1.2	1.5	2.9
1995-2007	0.3	0.7	0.9	1.9
2007-2015	0.1	0.7	-0.4	0.4
Germany				
1950-1973	0.4	2.3	2.5	5.2
1973-1995	0.3	1.1	1.3	2.7
1995-2007	0.0	1.0	0.7	1.7
2007-2015	0.1	0.5	0.0	0.6
UK				
1950-1973	0.5	1.5	1.4	3.4
1973-1995	0.4	0.9	1.3	2.6
1995-2007	0.4	1.2	1.0	2.6
2007-2015	0.1	0.4	-0.3	0.2
United States				
1950-1973	0.3	0.9	1.5	2.7
1973-1995	0.3	0.5	0.4	1.2
1995-2007	0.3	1.2	1.1	2.6
2007-2015	0.1	0.8	0.1	1.0

Notes:
labour productivity is measured in terms of output per hour worked;
estimates for 2007-15 are for the whole economy;
the growth accounting equation with which these estimates are derived is $\Delta \ln(Y/L) = \alpha \Delta \ln(K/L) + (1-\alpha)\Delta \ln E + \Delta \ln A$ where E is the educational quality of the labour force and A is total factor productivity (TFP). The method assumes that the data can be viewed as if there is a production function $Y = AK^{\alpha}(LE)^{1-\alpha}$.

Sources: 1950-1995: O'Mahony (1999); 1995-2007: van Ark (2011); 2007-15: The Conference Board (2016). Education contributions from 1950-1995 are estimated based on years of schooling in Morrisson and Murtin (2009).

Table 3. Estimates of Trend Productivity Growth (% per year)

	TFP			*Y/L*		
	2000	***2007***	***2015***	***2000***	***2007***	***2015***
France	0.7	0.3	0.3	1.1	0.8	0.5
Germany	0.7	0.5	0.5	1.1	0.6	0.2
UK	1.1	0.0	0.4	2.1	0.9	0.9
United States	1.1	0.9	0.7	2.0	1.5	1.0

Note: estimates obtained using an HP filter methodology.

Source: Ollivaud et al. (2016)

Table 4. GPTs: Contributions to Labour Productivity Growth (% per year)

	Capital-Deepening	*TFP*	*Total*
Steam (UK)			
1760-1830	0.011	0.003	0.014
1830-1850	0.16	0.04	0.20
1850-1870	0.20	0.21	0.41
1870-1910	0.15	0.16	0.31
Electricity (USA)			
1899-1919	0.34	0.06	0.40
1919-1929 (1)	0.23	0.05	0.28
1919-1929 (2)	0.23	0.75	0.98
ICT (USA)			
1974-1995	0.41	0.36	0.77
1995-2004	0.78	0.72	1.50
2004-2012	0.36	0.28	0.64

Memorandum Item: Real Price Falls (%)

Steam Horsepower	
1760-1830	39.1
1830-1870	60.8
1870-1910	50.0
Electric Motors (Sweden)	
1901-1925	38.5
ICT Equipment	
1970-1989	80.6
1989-2007	77.5

Notes:

Growth accounting estimates except 1919-1929 (2) based on the following equation:

$$\Delta(Y/L)/(Y/L) = \alpha\Delta(K_O/L)/(K_O/L) + \beta\Delta(K_{GPT}/L)/(K_{GPT}/L) + \omega(\Delta A/A)_{GPT} + \phi(\Delta A/A)_O$$

This equation decomposes the sources of labour productivity growth into contributions from two types of capital, GPT capital and other capital each weighted by their income shares, β and α, and two types of TFP growth in the production of GPT equipment and in the rest of the economy, each weighted by their shares in gross output, ω and ϕ. Thus, the GPT is allowed to have impacts on labour productivity growth both through a capital-deepening effect and through own TFP growth.

1919-1929 (2) includes an additional contribution from TFP spillovers.

Sources:

Growth accounting: Crafts (2002) (2004) and Byrne et al. (2013).

Price falls: Crafts (2004), Edquist (2010) and Oulton (2012)

Table 5. Contributions to TFP Growth in the U. S. Business Sector (% per year)

a) 1899-1941

	1929-1941	***1899-1941***
TFP Growth	1.86	1.29
Great Inventions	0.84 (0.35)	0.49 (0.27)
Other	1.02 (1.51)	0.80 (1.02)

b) 1974-2012

	1974-1995	***1995-2004***	***2004-2012***	***1974-2012***
TFP Growth	0.50	1.61	0.34	0.73
IT Sectors	0.36	0.72	0.28	0.43
Other	0.14	0.89	0.06	0.30

Note: following Gordon (2016) 'great inventions' comprise technology clusters around electricity, internal combustion engine, re-arranging molecules, communications & entertainment; figures in parentheses re-classify distribution as other.

Sources: Bakker et al. (2017); Byrne et al. (2013)

Table 6. R & D Expenditure (%GDP)

	R & D (GERD) 2000	*R & D (BERD) 2000*	*R & D (GERD) 2005*	*R& D (BERD) 2005*	*R & D (GERD) 2015*	*R & D (BERD) 2015*
France	2.08	1.30	2.04	1.27	2.23	1.45
Germany	2.39	1.68	2.42	1.68	2.87	1.95
UK	1.64	1.06	1.57	0.96	1.70	1.12
United States	2.62	1.94	2.51	1.73	2.79	1.99

Sources: OECD (2017)

Table 7. R & D and the Production of Ideas in the United States, 1955-2010 (1965 = 100)

	R & D	*(R & D)/GDP (%)*	*New Tech Books*	*Patents*
1955	68.2	1.45	51.8	
1965	100.0	2.72	100.0	100.0
1980	162.8	2.21	198.1	78.4
1995	258.1	2.40	301.2	124.2
2010	375.1	2.73		214.5

Notes: tech books based on titles in the catalogue of the Library of Congress; patents are those of domestic origin; all data are 5-year averages.

Sources: Alexopoulos and Cohen (2011); National Science Foundation (2017); United States Patent and Trademark Office (2016)

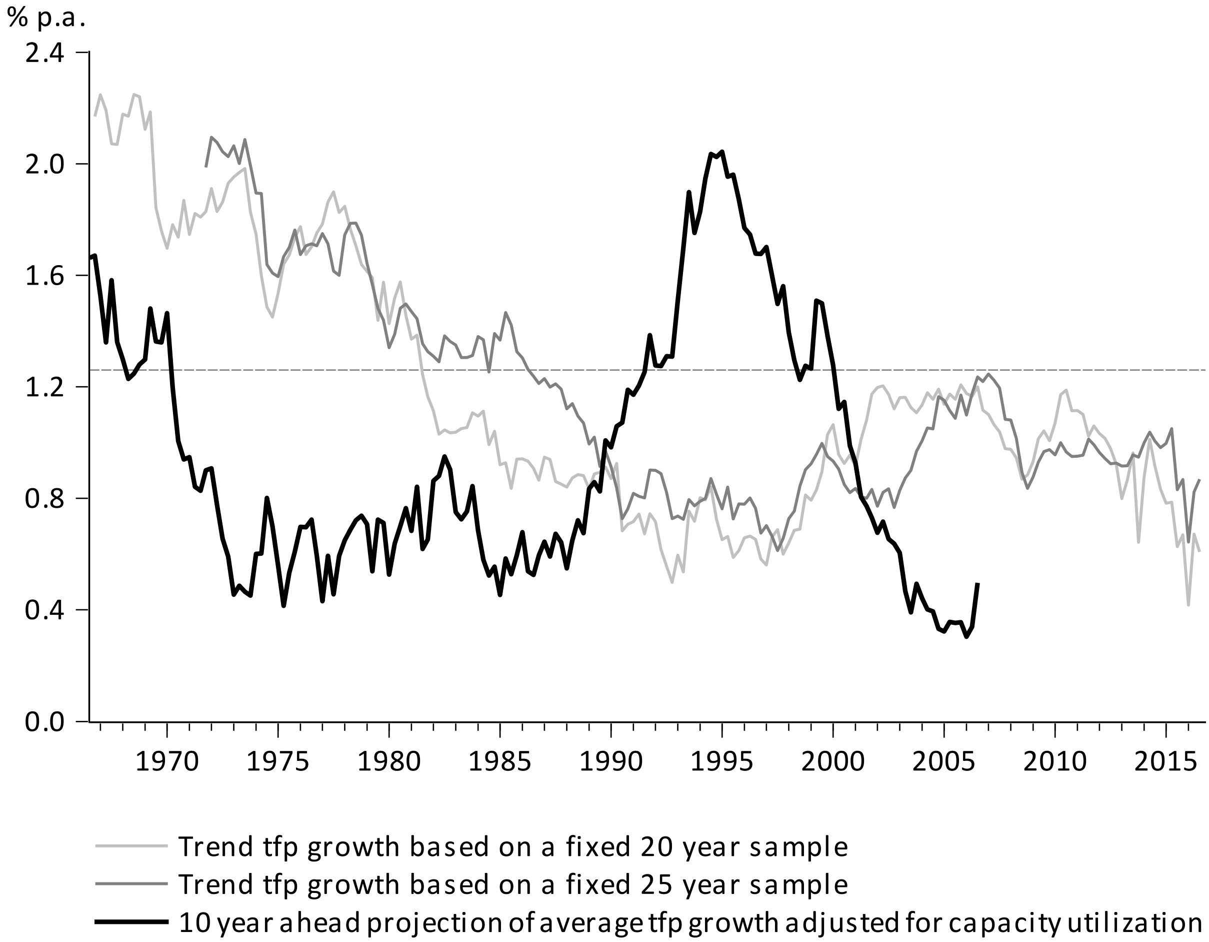

Figure 1. TFP Growth in the United States: Forecasts versus Outcomes

Source: Crafts and Mills (2017)